ORIGINAL ARTICLE

Recovery of cognitive and dynamic motor function following concussion

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Objective: Neuropsychological testing has been advocated as an important tool of proper post-concussion management. Although these measures provide information that can be used in the decision of when to return an individual to previous levels of physical activity, they provide little data on motor performance following injury. The purpose of this investigation was to examine the relationship between measures of dynamic motor performance and neuropsychological function following concussion over the course of 28 days.
Methods: Participants completed two experimental protocols: gait stability and neuropsychological testing. The gait stability protocol measured whole-body centre of mass motion as subjects walked under conditions of divided and undivided attention. Neuropsychological testing consisted of a computerised battery of tests designed to assess memory, reaction time, processing speed and concussion symptoms. Correlation coefficients were computed between all neuropsychological and gait variables and comparisons of neuropsychological and gait stability post-concussion recovery curves were assessed.
Results: Dynamic motor tasks, such as walking under varying conditions of attention, are complex and demanding undertakings, which require a longer recovery time following a concussion than cognitive measures. Little statistical relationship was found between the neuropsychological and gait variables, and the recovery curves of neuropsychological and gait domains were observed to be independent.
Conclusions: In order to fully examine the effects of concussion and determine the optimal time for a safe return to activity, a multi-factorial approach, including both cognitive and motor tasks, should be employed.

The effects of head injuries vary across affected individuals but commonly result in symptoms consisting of headache, dizziness, amnesia, attentional deficit and nausea.[1] Recent position statements by the National Athletic Trainers Association (USA) and the International Conference on Concussion in Sport have advocated a multi-factorial approach to concussion management.[2 3] Several methods have been proposed including neuropsychological (NP) and postural stability testing, and symptom checklists.[3]

A number of reports indicate that NP measures generally return to baseline in 5 to 7 days post-injury.[1 4–6] Other studies have found significant impact from concussion on other measures including reaction time (RT), information processing, and memory.[5 7–9] Collie *et al.*[7] found a significant difference in RT between concussed athletes who were still symptomatic 10 days following their injury and those who were asymptomatic at the time of testing. In a study of boxers, RT failed to return to baseline by day 14.[5] Although each of these studies reported different recovery windows, RT was consistently found to be a sensitive measure of concussion.

Speed of information processing has also been noted to decline in concussed individuals. In a prospective study of professional rugby players it was found that failure to improve on tests of visual motor processing was enough to distinguish concussed athletes from controls.[10] Other research has determined that attenuation of practice effects, or failure to improve on serial testing, is a sufficient criterion for determination of concussion in the absence of other group differences.[5 7 11]

Recent research has indicated that centre of mass (COM) motion is a sensitive measure of gait stability following concussion.[12–15] Dynamic motor assessment, such as gait analysis, may better approximate activities of daily living than static measures, and can provide more extensive information about the necessary motor skills that a concussed individual would need to return to pre-injury levels of activity. It has been demonstrated that medial-lateral sway and sway velocity of concussed subjects are significantly greater than controls for up to 28 days post-injury when subjects walked while simultaneously performing cognitive tasks.[14 15] In addition, gait velocity and the separation distance between the COM and centre of pressure (COP) were diminished in concussed individuals compared with uninjured controls, over similar post-injury time periods.[14 15]

NP testing has been advocated as an important tool of post-concussion management.[3] Although NP measures provide information on cognitive ability, they do not provide data on post-concussion motor function, which is an important parameter in evaluating when an athlete may safely return to sport following head injury. Since the association between post-concussion NP function and motor function has not yet been determined, the purpose of this investigation was to examine the relationship between measures of dynamic motor performance and NP function over the course of 28 days following concussion.

METHODS

Fifty-eight college-aged men and women served as subjects for this study and were categorised into two groups. The groups consisted of National Collegiate Athletic Association (NCAA, USA) athletes, university club sport athletes and other university students who sustained a concussion (CONC) and those who served as uninjured controls (NORM). The CONC group subjects (n = 29) had sustained a Grade 2 concussion according to the American Academy of Neurology Practice

Abbreviations: COM, centre of mass; CONC, concussion group; COP centre of pressure; ImPACT, immediate Postconcussion Assessment and Cognitive Testing battery; NORM, uninjured control group; NP, neuropsychological; RT, reaction time; VMPS, visual motor processing speed

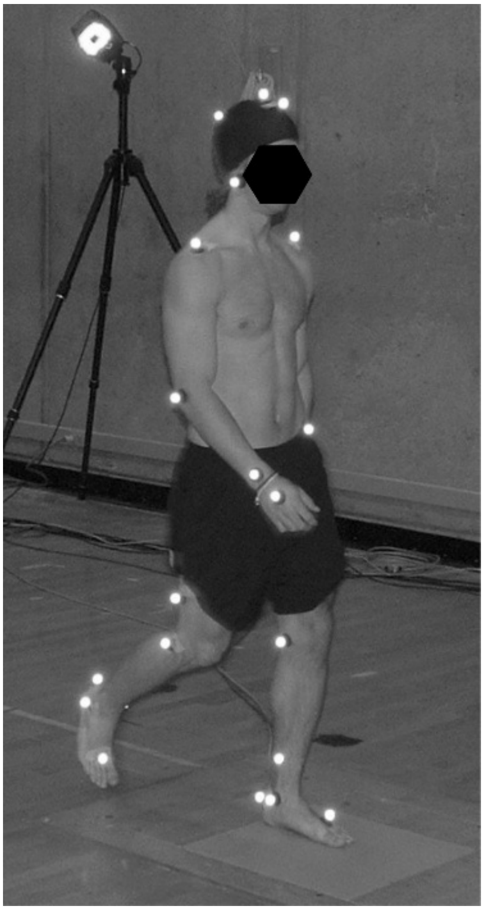

Figure 1 Subject with markers approaching force plate. Informed consent was obtained for publication.

Parameter, which entails transient confusion with symptoms lasting more than 15 min.[16] These subjects were initially identified by sports injury specialists (Certified Athletic Trainers, USA) and attending medical doctors in the university intercollegiate sports programme and the university student health centre, and were referred for testing. The NORM group subjects (n = 29) were individually matched to the concussed subjects by sex, age, height, weight and physical activity. None of the participants had a history of concussion within the last year, or a history of neurological diseases, uncorrected visual impairment, musculoskeletal impairments, or persistent symptoms of vertigo, lightheadedness, unsteadiness or falling.

The experimental protocols were approved by the Institutional Review Board and the participants completed two experimental protocols: gait stability and NP testing. Both procedures were explained to all subjects prior to testing and verbal and written consents were obtained.

Gait stability testing

All CONC subjects were tested within 48 h of injury (day 2) and again at 5, 14, and 28 days post-injury. The NORM participants were tested at the same time intervals. All subjects were tested barefoot to avoid inter-subject shoe type differences in style and wear patterns, which could alter gait and confound marker placement. The participants were instructed to walk along a 10-m walkway at their preferred walking speed. The gait protocol was the same for each testing day and consisted of level walking under two conditions: (1) with undivided attention (single-task); and (2) while simultaneously completing simple mental tasks (dual-task). These concurrent tasks consisted of spelling five-letter words in reverse, subtraction by sevens and reciting the months of the year in reverse order; these tests have been used frequently in mental status examinations to assess attention and concentration.[17] Each type of dual-task was completed by every subject with the order of individual tasks rotated across trials.

In order to assess gait variables, a set of 31 reflective markers were placed on bony landmarks of the participant (fig. 1). A more detailed description of marker placement was reported previously.[18] An eight-camera motion analysis system (Motion Analysis Corp., Santa Rosa, CA, USA) was used to capture and reconstruct the three-dimensional trajectory of the surface markers. Virtual marker positions were estimated using EVaRT software (Motion Analysis Corp.) to represent joint centres and positions of the segmental COM from the external markers. Anthropometric reference data were adapted from Dempster.[19] Whole-body COM position was calculated as the weighted sum of each body segment, with 13 segments representing the whole body (head–neck, trunk, pelvis, arms, forearms, thighs and feet). Velocities of the COM were estimated using the generalised cross-validated spline algorithm.[20] To compute the COP, ground reaction forces were collected by two force plates (Advanced Mechanical Technology, Watertown, MA, USA) positioned in series along the gait path.

Variables were examined in one gait cycle, which was defined as heel strike on the force plate to the next heel strike of the same limb. Four gait stability variables were utilised for comparison with NP measures: COM displacement and peak velocity in the medial-lateral direction (MLdisp; MLvel), average gait velocity (GV), and the maximum separation between the COM and COP in the anterior direction (ANTmax; fig. 2).

NP testing

NP function was assessed at the same time intervals as gait testing with the Immediate Postconcussion Assessment and Cognitive Testing battery (ImPACT; ImPACT Applications, Pittsburg, PA, USA). This battery was designed specifically for sports-related concussion and consisted of six individual test modules that assess attention, memory, reaction time and processing speed, as well as the assessment of concussion symptoms.[21] Three composite NP scores (visual memory, choice RT and processing speed) and subject rating of concussion symptoms comprised the four dependent variables that were assessed. For choice RT, the average speed of responding to symbol-matching, colour-matching and left–right side matching tasks comprised the score. For concussion symptoms, the subjects rated the current severity of 22 commonly reported post-concussion symptoms, via a Likert scale, yielding a total symptom score. The symptom score included items related to headache, nausea, balance, dizziness, fatigue, drowsiness, sleep, mood, concentration, memory, confusion and vision.[22,23]

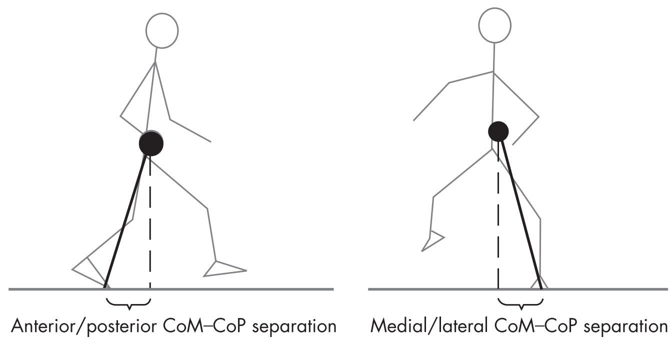

Figure 2 Schematic representation of the relationship between the COM and COP.

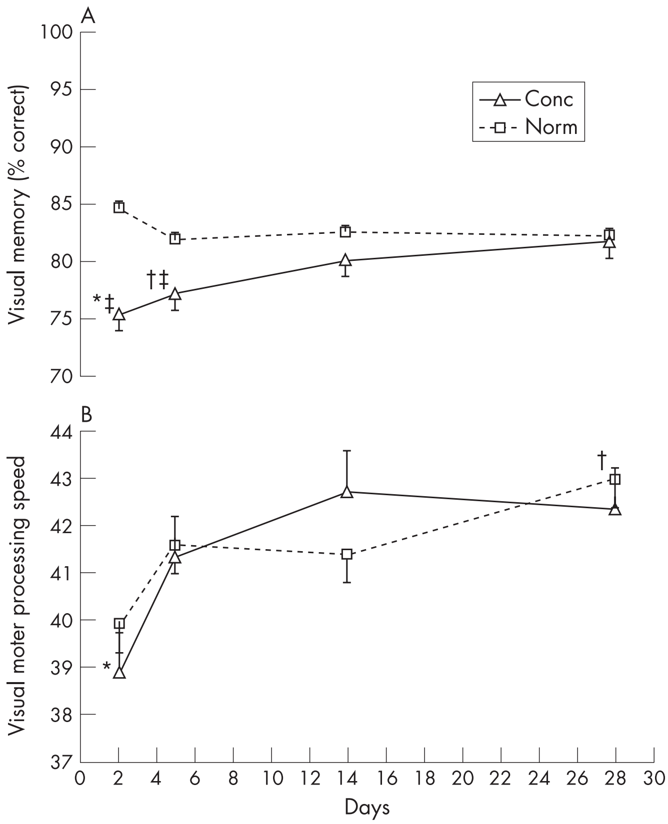

Figure 3 (A) Visual memory composite scores (with standard errors) for the CONC and NORM groups across testing days. *Significantly less than day 5; †significantly less than day 14; ‡significantly less than NORM. (B) Visual motor processing speed composite scores (with standard error). *Significantly less than days 5, 14, 28; †significantly greater than days 2, 5. All $p<0.05$.

Three-way analyses of variance (ANOVAs) were used to determine the effects of group (CONC versus NORM), task (single versus dual) and testing day (2, 5, 14, and 28) for the gait variables ($p<0.05$). Two-way ANOVAs were computed to determine the effects of group and day for the NP variables ($p<0.05$). To determine the relationship between gait and NP measures, Pearson's correlation coefficients were computed for combined groups and between all combinations of the cognitive and gait variables (SPSS Inc., Chicago, IL, USA).

Gait velocity was found to have task × group ($p = 0.031$) and task × day ($p = 0.007$) interactions (fig 6b). Both groups were significantly slower during dual-task than single-task on all days.

RESULTS

No significant differences in anthropometric data were found between the CONC and NORM groups (table 1).

Visual memory was found to have a day × group interaction effect ($p = 0.047$). The NORM group showed no significant change on any day while the CONC group showed significant improvement from day 2 to 5 and from day 5 to 14 (fig 3). In addition, significant group differences were detected for the testing days 2 and 5 with the CONC group performing worse than controls.

Visual motor processing speed (VMPS) had a day effect ($p = 0.001$) with the NORM group improving through day 28. Specifically, VMPS was significantly faster on day 28 than on days 2 and 5 (fig 3). The CONC group mean processing speed was significantly faster on day 5 compared with day 2 but did not change significantly after day 5. No significant between-group differences were observed for VMPS.

RT displayed a day × group interaction ($p = 0.024$) with the CONC group improving significantly from day 2 to 5 (fig 4). Group differences were found only on day 2 with the CONC group RT significantly slower than controls.

The symptom composite score was significantly greater for the CONC group compared with controls on days 2, 5, and 14 (day × group interaction, $p = 0.001$). Each test between days 2 and 14 showed significant improvement in symptoms for the CONC group (fig 4) while the NORM group did not differ across days.

Performance (error rate) on the mental tasks comprising the dual-task condition was not different between groups regardless of day. Medial–lateral COM displacement and velocity showed task effects ($p = 0.001$) for both groups at day 2; however, the CONC group continued to have significantly greater sway for the dual-task condition on days 5 and 28. Dual-task COM displacement decreased by day 5 for both groups, but these differences were not significant. Peak medial–lateral sway velocity remained relatively stable over the four testing days (fig. 5b); however, the dual-task produced significantly faster sway than the single-task condition for both groups, even at 28 days following initial testing.

Maximum anterior COM–COP separation distance revealed a task effect ($p = 0.001$), with the dual-task producing a smaller separation distance than the single-task for the CONC group on all days. A day × group interaction ($p = 0.040$; fig 6) was also observed as the CONC group exhibited significantly greater separation on day 2 than day 5, while the NORM group showed significantly greater separation on day 28 than days 2 and 5.

Low to moderate, but significant, correlations were found between RT and dual-task medial–lateral sway ($r = 0.401$, $p = 0.003$), and between RT and sway velocity ($r = 0.\ 317$, $p = 0.022$) only for the first day of testing (fig 7). All other correlation coefficients were not statistically significant.

DISCUSSION

The results revealed a recovery pattern of improvement over time following concussion for all of the NP variables, while the NORM group showed no significant changes in three of four variables studied: visual memory, RT and symptom score.

For the CONC group, RT returned to the NORM level at day 5, which is a shorter time frame than some previous studies on concussed subjects.[5 7 8] Collie and colleagues[7] found that RT was significantly affected in symptomatic, but not asymptomatic athletes. Other investigators measured simple RT and found that group differences persisted until 10 days post-injury,[5] and that choice RT (correct compared with incorrect responses) was slowed for up to 1 month after injury.[24] One possible explanation for the discrepancy between studies may be in the manner of RT computation. In the present study, a composite RT was derived from three different modules. This computation may have diluted between-group differences in RT findings beyond the second testing session.

It has been shown previously that individuals with mild,[14 15] moderate and severe traumatic brain injury[25] exhibited residual deficits in gait and balance control under complex dual-task conditions compared with controls. In this study, RT was significantly correlated to the medial–lateral variables of sway and sway velocity in the first 2 days following injury. Although the small shared variance (10–16%) between RT and COM motion has little predictive power, it is of interest to note that the correlations were only significant in the dual-task condition. Further analysis revealed that these associations were not significant in the uninjured control group (MLdisp $r = 0.117$; MLvel $r = 0.197$) implying that this relationship may be, in part, due to brain injury sustained by the CONC group. Haggard et al.[26] reported a significant correlation between dual-task

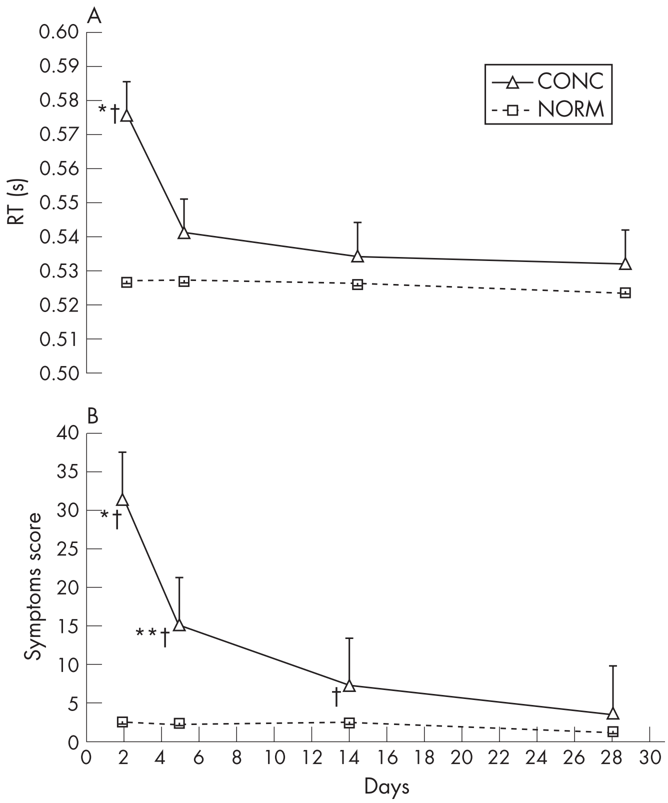

Figure 4 (A) Reaction time composite (with standard error) for the CONC and NORM groups across testing days. *Significantly slower than days 5, 14, 28; †significantly slower than NORM. (B) Symptom scores (with standard error). *Significantly greater than day 5; †significantly greater than day14; ‡significantly greater than NORM. All $p<0.05$.

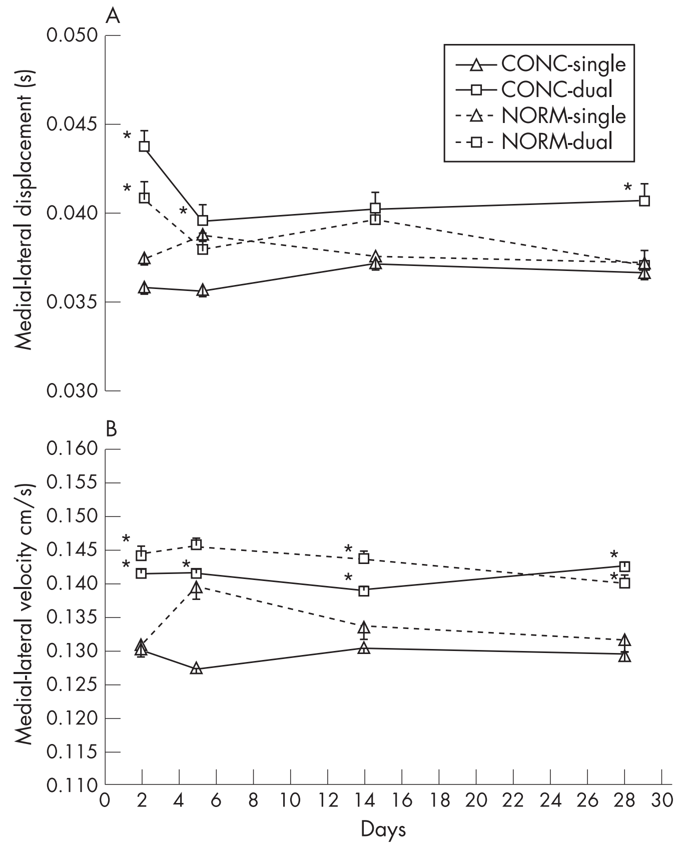

Figure 5 (A) Medial–lateral COM excursion (with standard error) for the CONC and NORM groups across testing days and between tasks. *Significantly greater than single-task. (B) Medial–lateral COM peak velocity (with standard error). *Significantly greater than single-task. All $p<0.05$.

decrements and activities of daily living in patients with acquired non-progressive brain injury.

Visual memory scores for the CONC group were poorer than controls in the first 5 days following concussion, but returned to NORM values by day 14. Although the precise day of recovery for this variable was not determined, the possible range (day 5 to day 14) is not inconsistent with data from McCrea et al.,[4] who reported verbal memory returning to normal by day 7 post-injury. The present investigation focused on visual, rather than verbal memory, which may require a somewhat longer recovery time.

For VMPS, the control group showed improvement over time, possibly due to practice effects, with the final testing day producing the greatest score. However, the concussed group did not show evidence of a practice effect, but displayed a leveling of scores with no significant improvement after day 5. This lack of improvement by the CONC group, or attenuation of practice effects, has been shown to be sensitive to concussed individuals.[5 10]

Recovery on the symptoms score composite resembled findings found in the literature, although the present study reported a somewhat longer recovery time frame.[4 8 11] This may possibly be due to methodological differences between studies, whereas symptoms recovery, in the current investigation, was based on comparisons with matched controls, rather than to individual baseline values commonly reported in the literature. CONC group symptom scores were highest (mean 31.33) on the first testing session and continued to be higher than controls through the third testing session. Not unexpectedly, the control group average score was very low (mean 2.13) and showed no significant changes across time. McCrea et al.[4] found that the majority of concussed athletes returned to baseline measures of symptoms by day 7 while and Warden and colleagues[8] reported symptom recovery at 4 days post-injury.

When comparing the recovery curves of the NP cognitive and motor domain variables, the cognitive scores tended to delineate the CONC group from the NORM group for the first two testing sessions, after which no significant between-group differences were observed. One exception to this trend was for symptom scores which did not normalise until after day 14. The motor domain sagittal plane variables of gait velocity and COM–COP separation distance tended to mirror the cognitive recovery curves initially, however, the dual-task resulted in significantly slower gait and less COM–COP separation than the single-task condition for both groups across the testing sessions. Medial-lateral sway velocity did not show a typical recovery pattern, but rather steady within-group data. Similar to the sagittal gait variables, the dual-task resulted in significantly greater sway velocity than the single-task condi-

Table 1 Group characteristics and initial testing time

	CONC		NORM		
Characteristic	Mean	SD	Mean	SD	p Value (t test)
Age (year)	21.60	3.26	21.38	3.40	0.78
Height (m)	1.76	0.11	1.76	0.12	0.7
Weight (kg)	81.82	24.16	83.31	23.66	0.81
Sex (men/women)	15/14		15/14		
Time from injury to initial testing (h)	34.26	11.78	NA		

NA, not applicable.

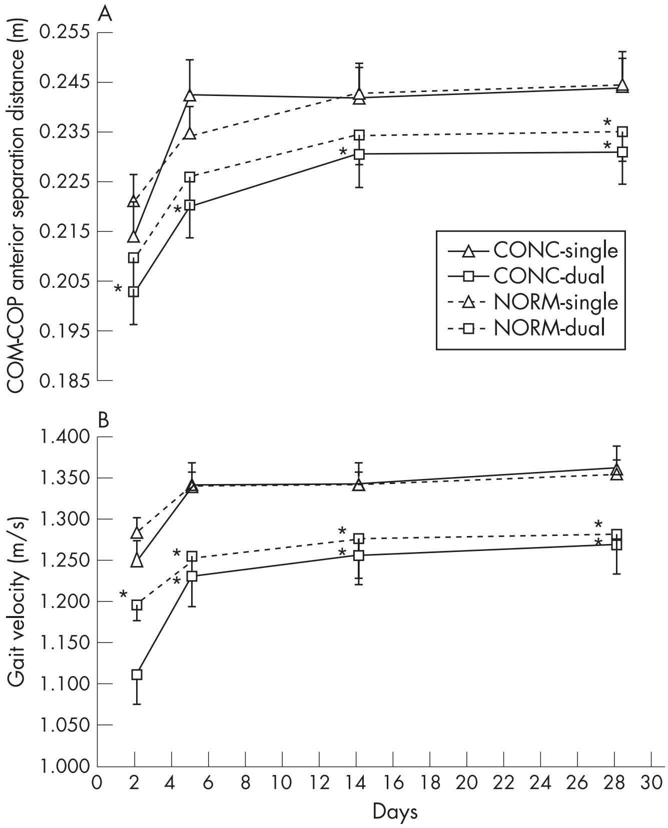

Figure 6 (A) Anterior separation distance between the COM and COP (with standard error) for the CONC and NORM groups across testing days and between tasks. *Significantly less than single-task. (B) Average gait velocity (with standard error). *Significantly less than single-task. All $p<0.05$

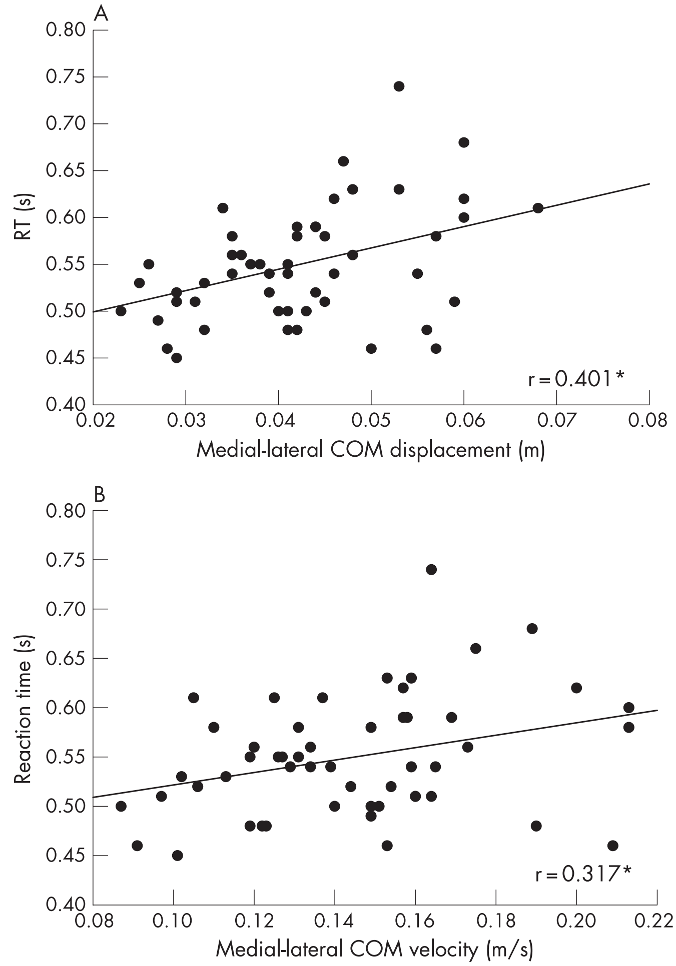

Figure 7 Regression lines and correlations between (A) the medial-lateral COM displacement and reaction time and (B) the medial-lateral COM peak velocity and reaction time for all subjects on the first day of testing (within 48 h of injury). $*p<0.05$.

tion across testing sessions. The medial-lateral sway for the NORM group under the dual-task condition did not alter from single-task values after the initial testing. However, the CONC group followed the pattern of the controls until day 14, after which it separated further from the single-task condition and was significantly different at day 28 (fig 5a). These data suggest that cognitive and motor effects of concussion may resolve differently.

NP variables, other than those found in ImPACT, may show stronger relationships to the resolution of gait deficits following injury. The Attentional Network Testing[27] permits the examination of alerting (arousal), orienting (covertly directing sensory processes to spatial regions) and executive (task switching) components of visuospatial attention. In a test to examine the extent to which deficits in such components recovered following concussion, Halterman *et al*.[24] found that the orienting deficit resolved within the first week of the injury, whereas the executive or conflict component deficit remained 1 month after injury.

An effort was made to control for potentially confounding variables through strict matching of concussed and uninjured participants. However, some elements, such as concussion history, were not controlled. Although none of the subjects had sustained a concussion for at least 1 year prior to this study, head injuries prior to 1 year were not incorporated into the matching formula.

Despite these limitations, the findings of the present study indicate that there is little relationship between NP measures from the ImPACT battery and gait stability variables. This conclusion is further supported by examination of cognitive and motor domain longitudinal recovery curves.

NP tests measure specific aspects of memory, processing speed, and reaction time in the days following concussion. However, these measures generally resolve within several days after injury. Dynamic motor tasks, such as walking under varying conditions of attention, are complex and demanding undertakings, which require a longer recovery time following a

What is already known on this topic?

- NP testing has been advocated as an important tool of post-concussion management.
- Recent research reported that centre of mass motion is a sensitive measure of gait stability following concussion.

What this study adds?

- A weak statistical relationship was found between the NP measures from the ImPACT battery and gait variables.
- Tests of complex motor performance may better approximate the demands placed on an individual during sports participation and activities of daily living than cognitive assessment alone.

concussion than cognitive measures. Likewise, tests of complex motor performance may better approximate the demands placed on a subject during sports participation and activities of daily living than cognitive assessments alone.

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Competing interests: None.

REFERENCES

1 **Johnston KM**, McCrory P, Mohtadi NG, *et al.* Evidence-based review of sport-related concussion: clinical science. *J Sport Med* 2001;**11**:150–9.
2 **McCrory PK**, Johnston, M, Meeuwisse W, et al. Summary and agreement statement of the 2nd International Conference on Concussion in Sport, Prague 2004. *Br J Sports Med* 2005;**39**:196–204.
3 **Guskiewicz KM**, Bruce SL, Cantu RC, *et al.* National Athletic Trainers' Association position statement: management of sport-related concussion. *J Ath Train* 2004;**39**:280–97.
4 **McCrea M**, Guskiewicz KM, Marshall SW, *et al.* Acute effects and recovery time following concussion in collegiate football players: the NCAA concussion study. *JAMA* 2003;**290**:2556–63.
5 **Bleiberg J**, Cernich AN, Cameron K, *et al.* Duration of cognitive impairment after sports concussion. *Neurosurgery* 2004;**54**:1073–8.
6 **Belanger HG**, Vanderploeg RD. The neuropsychological impact of sports-related concussion: a meta-analysis. *J Int Neuropsych Society* 2005;**11**:345–57.
7 **Collie AD**, Makdissi M, Maruff P, *et al.* Cognition in the days following concussion: comparison of symptomatic and asymptomatic athletes. *J Neurol Neurosurg Psychiatr* 2006;**77**:241–5.
8 **Warden DL**, Bleiberg J, Cameron KL, *et al.* Persistent prolongation of simple reaction time in sports concussion. *Neurobiology* 2001;**57**:524–6.
9 **Peterson CL**, Ferrara MJ, Mrazik M, *et al.* Evaluation of neuropsychological domain scores and postural stability following cerebral concussion in sports. *Clin J Sport Med* 2003;**13**:230–7.
10 **Hinton-Bayre AD**, Geffen G, McFarland K. Mild head injury and speed of information processing: a prospective study of professional rugby league players. *J Clin Exp Neuropsychol* 1997;**19**:275–89.
11 **Macciocchi SN**, Barth JT, Alves WM, *et al.* Neuropsychological functioning and recovery after mild head injury in collegiate athletes. *Neurosurgery* 1996;**39**:510–4.
12 **Chou L-S**, Kaufman KR, Walker-Rabatin AE, *et al.* Dynamic instability during obstacle crossing following traumatic brain injury. *Gait Posture* 2004;**20**:245–54.
13 **Basford JR**, Chou L-S, Kaufman KR, *et al.* An assessment of gait and balance deficits after traumatic brain injury. *Arch Phys Med Rehabil* 2003;**84**:343–9.
14 **Parker TM**, Osternig LR, Lee H-J, *et al.* The effect of divided attention on gait stability following concussion. *Clin Biomech* 2005;**20**:389–95.
15 **Parker TM**, Osternig LR, van Donkelaar P, *et al.* Gait stability following concussion. *Med Sci Sports Exerc* 2006;**38(6)**:1032–1040.
16 **American Academy of Neurology**. Practice parameter. The management of concussion in sports (summary statement). *Neurology* 1997;**48**:581–5.
17 **Bell RR**, Hall C. The mental status examination. *Am Fam Physician* 1977;**16**:145–52.
18 **Hahn, ME, Chou L-S**. Age-related reduction in sagittal plane center of mass motion during obstacle crossing. *J Biomech* 2004;**37**:837–44.
19 **Winter DA**. *Biomechanics and Motor Control of Human Movement.* New York: John Wiley & Sons, 1990:56–7.
20 **Woltring HJ**. A FORTRAN package for generalized, cross-validatory spline smoothing and differentiation. *Adv Eng Software* 1986;**8**:104–13.
21 **Iverson GL**, Lovell MR, Collins MW. Interpreting change on ImPACT following sport concussion. *Clin Neuropsychol* 2003;**17**:460–7.
22 **Aubry M**, Cantu R, Dvorak J, *et al.* Summary and agreement statement of the first international conference on concussion in sport, Vienna 2001. *Phys Sport Med* 2002;**30**:57–62.
23 **McCrory P**, Johnston K, Meeuwisse W, *et al.* Summary and agreement statement of the 2nd International Conference on Concussion in Sport, Prague 2004. *Clin J Sport Med* 2005;**15**:48–55.
24 **Halterman CI**, Langan J, Drew A, *et al.* Tracking the recovery of visuospatial attention deficits in mild traumatic brain injury. *Brain* 2006;**129**:747–53.
25 **Valee M**, McFayden BJ, Swain B, *et al.* Effects of environmental demands on locomotion after traumatic brain injury. *Arch Phys Med Rehabil* 2006;**87**:806–813.
26 **Haggard P**, Cockburn J, Cock J, *et al.* Interference between gait and cognitive tasks in a rehabilitating neurological population. *J Neurol Neursurg Psychiatry* 2000;**69**:479–486.
27 **Fan J**, McCandliss BD, Sommer T, *et al.* Testing the efficiency and independence of attentional networks. *J Cognitive Neurosci* 2002;**14**:340–7.

COMMENTARY 1

I believe this paper provides support for the notion that concussion identification and management is complex and requires a multifaceted approach. While a significant majority of the recent literature has been focused on neuropsychological testing, it is important to remember that concussions can result in a motor decrement, and that the recovery of neuropsychological and functional motor variables may not correlate. Thus, the prudent clinician should strive to assess and monitor multiple domains of function during the management of concussion.

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COMMENTARY 2

The authors have provided important observations regarding the independence of results from the ImPACT test and laboratory measures of locomotor ability. We have recently found[1] that certain tests of visuospatial attention and executive function can correlate to locomotor behaviour following moderate to severe traumatic brain injury. Whether this is an issue of injury severity, types of tests used or both needs to be considered further. As noted by the authors, both cognitive and motor tasks should be assessed in order to make better judgements about residual abilities and reintegration into activities for persons with brain injury of any severity.

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REFERENCE

1 **Cantin JF**, McFadyen BJ, Doyon J, Swaine B, Dumas D, Vallée M. Can measures of cognitive function predict locomotor behaviour in complex environments following a traumatic brain injury? *Brain Injury* 2007;**21**:327–34.